Dynamic Control of Grid Assets Using Direct AC Converter Cells

Deepak Divan* J. Rhett Mayor** Frank Lambert*

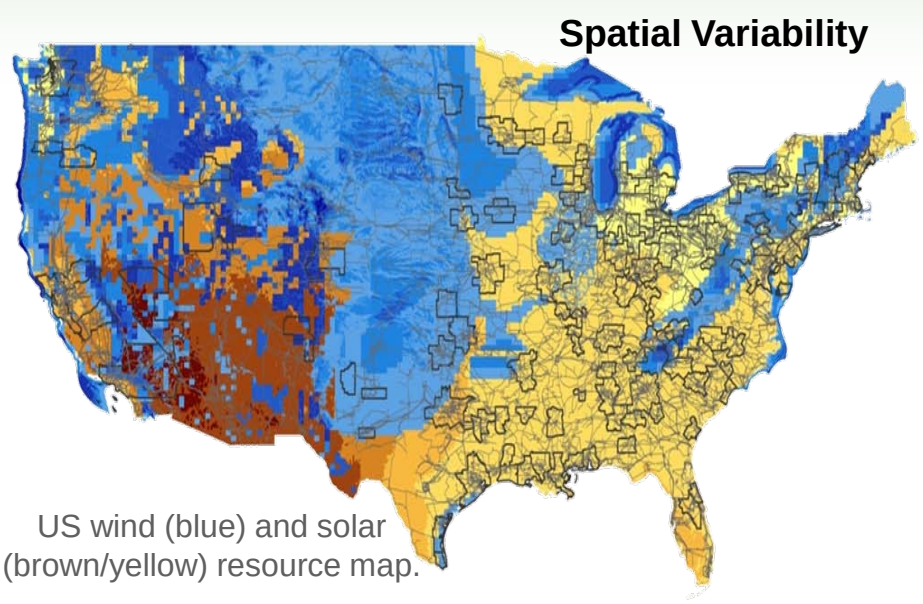
Georgia Institute of Technology

*School of Electrical & Computer Engineering
**School of Mechanical Engineering

Critical Issues for the Grid

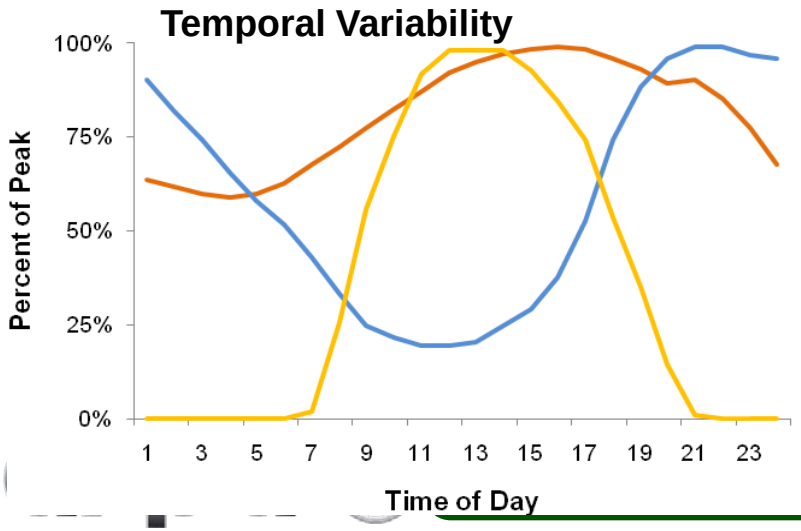
- Key initiatives:
  - Increased electrification for transportation
  - Increased renewables (wind, PV, etc.), driven by RPS mandates
- Forecast: 2x Generation and load in 20 years
- Spatial and temporal variability of new sources/loads will require grid power flow control and enhanced system capacity utilization
- Improved network control can reduce additional generation by ≤ 50%, and reduce T&D investments by ≤ 80%.

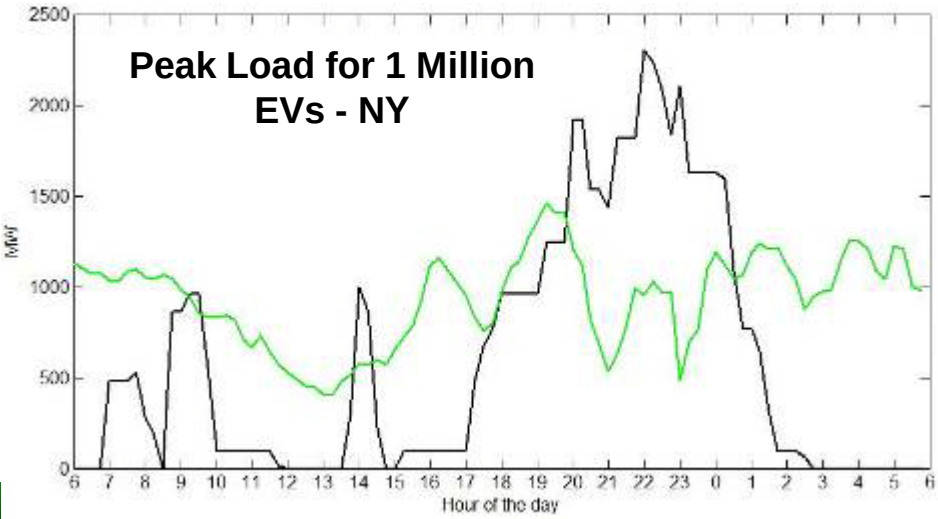
Challenges in Sustainable Electricity Generation



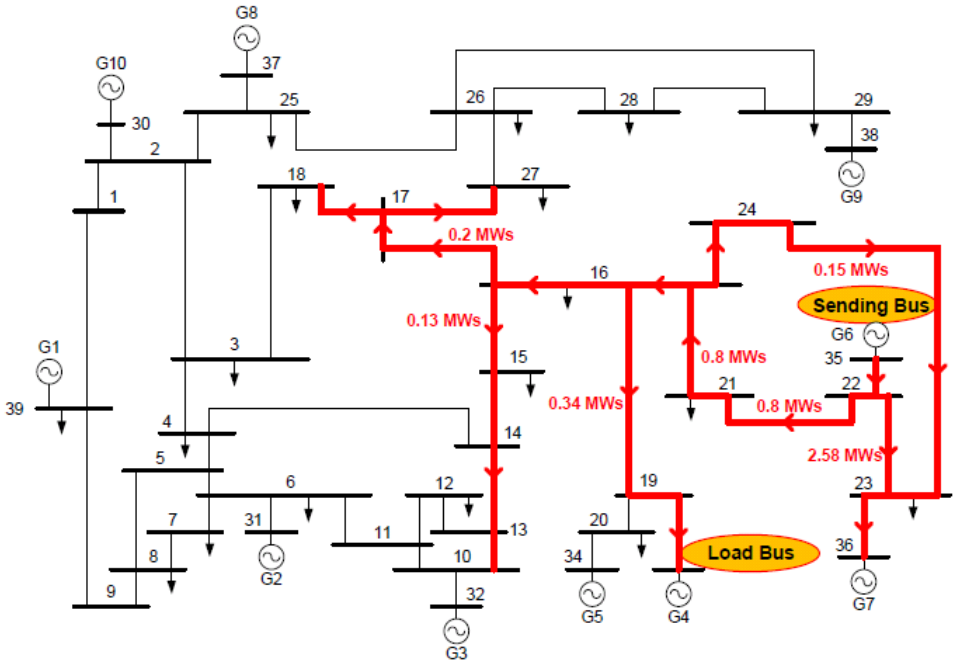
US wind (blue) and solar (brown/yellow) resource map.

- Binding RPS mandates of 10-40% in 27 states
- To meet reliability standards, new solar/wind plants need energy storage, back-up fossil plants & spinning reserve
- EVs require spinning reserve and new generation

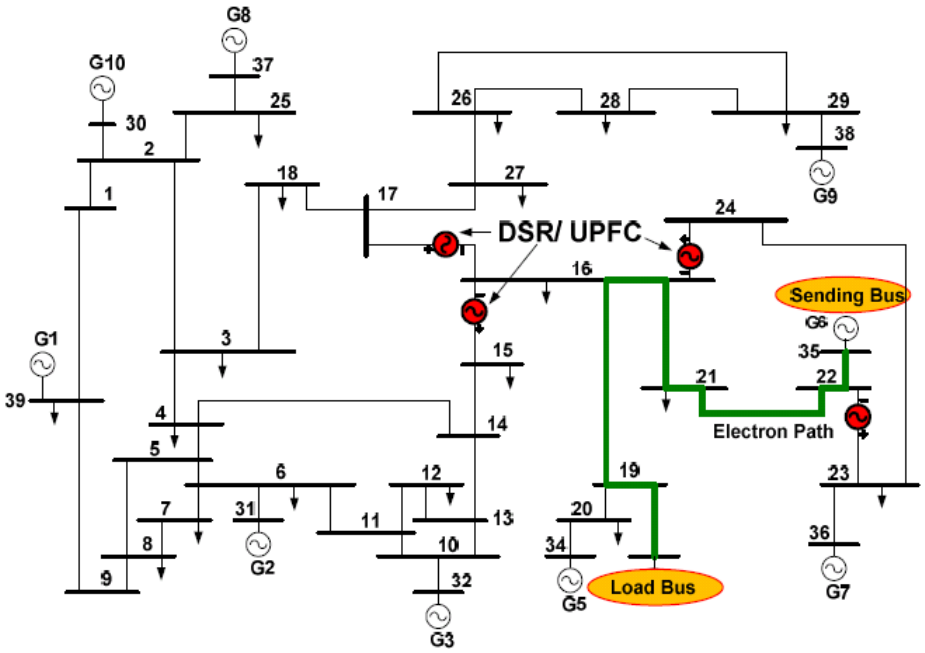




Controlling Energy Flows



Base Case: 3.4 MW sent; 0.34 MW recd



PCAT Case: 3.4 MW sent; 3.4 MW recd

Simplified IEEE 39 Bus system. 4 control areas. 20 yrs of operation w 20% RPS phased in. Transmission capacity added each year to eliminate curtailment of renewable generation.

- Business As Usual = upgrade of 3 inter-regional paths, 186,000 MW-MILES
- Smart Grid w/ power flow control = 36,000 MW-miles, 20% of BAU!

Dynamic Grid Control

FACTS (Flexible Alternating Current Transmission Systems) devices for controlling power quality

- Static VAR compensators
- STATCOM compensator/regulators
- Adaptive VAR compensators
- DC/AC Inverters

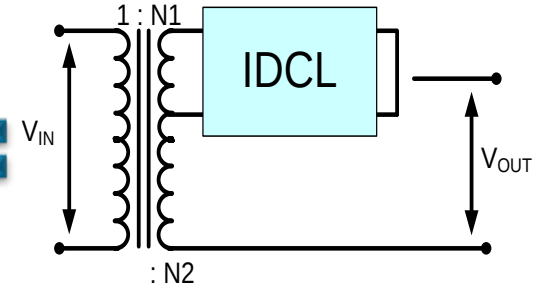
"FACTS limited by high cost & reliability (99.999% desired vs. 96-97%)"

Power Converter Augmented Transformer

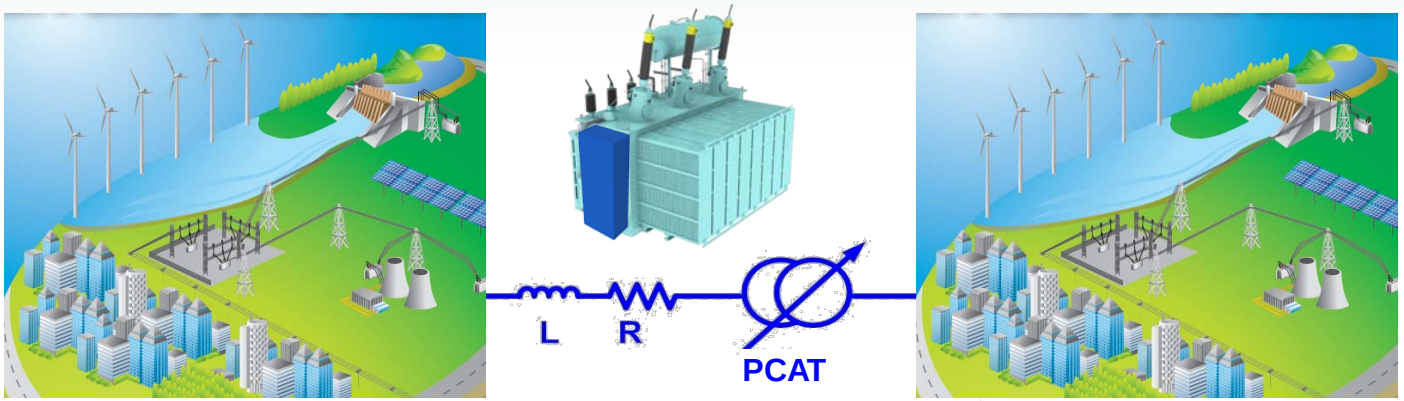
- Fail-normal, to maintain system reliability
- Potentially lower cost, fractionally rated converters
- Passively cooled converter – greater reliability
- Dynamic bidirectional control of real & reactive power flow (VQS)

LTC Transformer (Grid Asset)

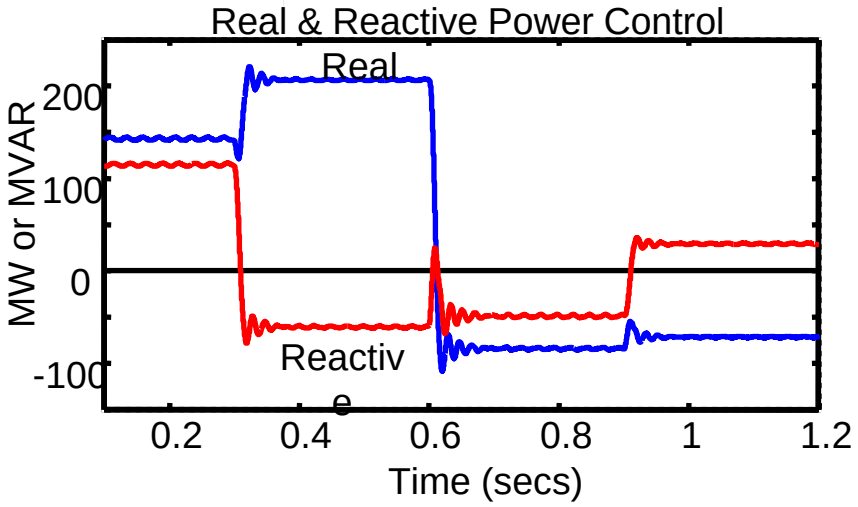
Imputed DC-Link (IDCL) Converter



Simulated Performance



- Dynamic real and reactive power flow control
- PCAT connection two regions
- No inverter
- Small fraction of the cost!
- The IDCL rating is 20% of power delivered
- Lower rating than B2B or UPFC converters



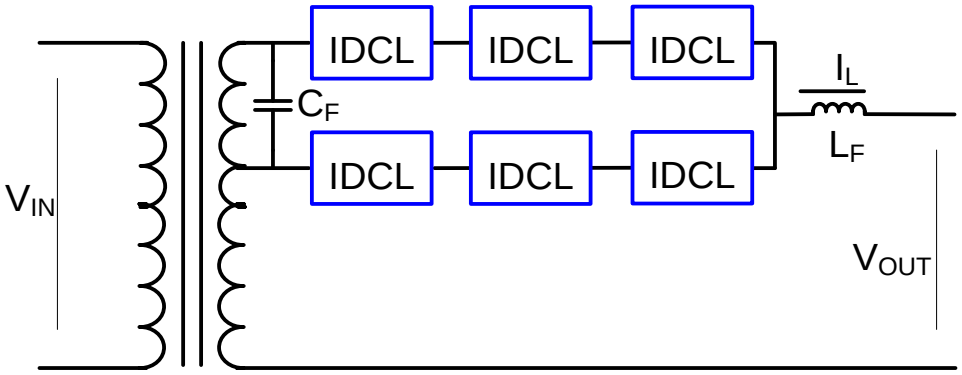
1 MW Power Converter Augmented Transformer (PCAT)

With Si-C devices:

- 12 IDCL cells will be built with 1200V, 20A DMOSFETS and 50A Schottky diodes
- Demonstrate 50 kHz switching through phase staggering => to reduce switching losses
- PCAT function demonstrated at 13 kV, or at rated current of 70 A, but not both

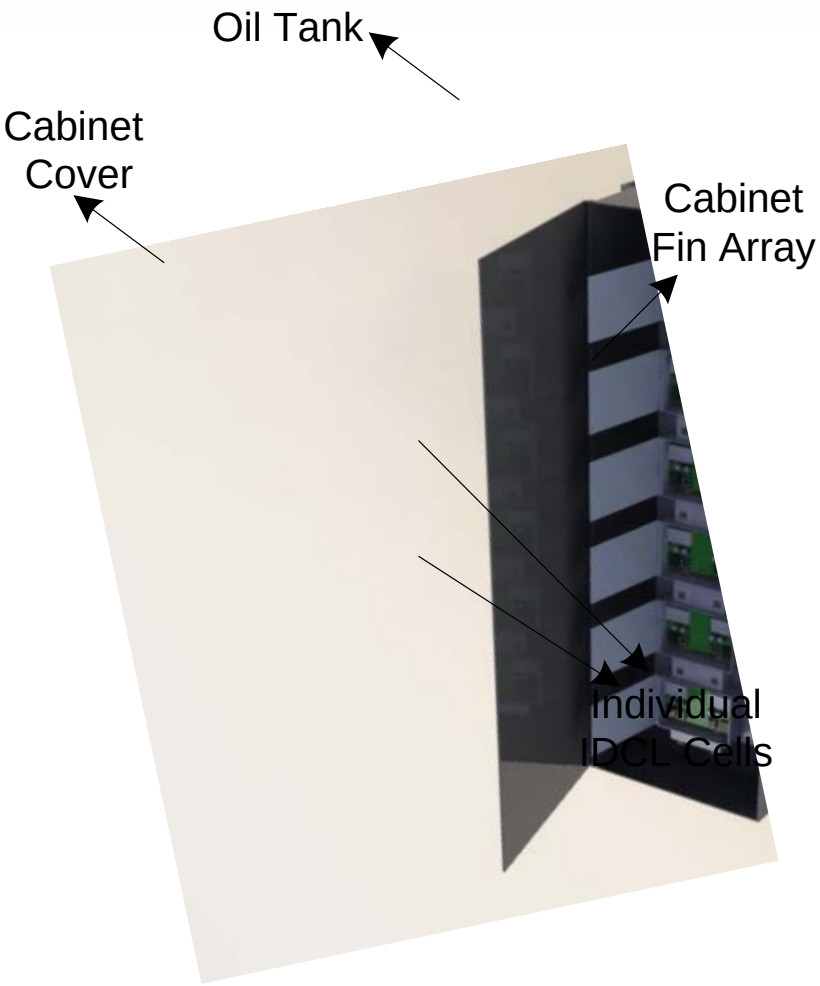
With Si devices:

- Three IDCL cells with 3300V or 1700V, 400A IGBT devices
- Demonstrate full voltage and power, but not 50 kHz operation



Challenges: Thermal Management & Packaging

- Long life: 30 yrs
- Outdoors installation with ambient T range: -40^{o}C to +55^{o}C
- Compact and modular packaging
- Fatigue due to thermal cycling
- High di-electric stress (100's of kV), dv/dt and di/dt
- Fault currents of up to 50 kA



ARPA-E Target Demonstration

- Power Converter Augmented Transformer (PCAT)
- Modular stackable concept
- Imputed DC Link Converter (IDCL) Cells
- Control 1 MW at 13 kV
- 98% efficiency and 50 kHz